Computation of Seismic Waveforms in Complex Media:
Carbon Dioxide Sequestration Imaging

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Research Objectives

The underground sequestration of CO2 presents a subsurface monitoring problem requiring new approaches. This CO2 specific problem is an important example of the need for effective tools applicable to subsurface imaging problems. Seismic tomographic imaging methods are compromised severely when the target region and/or the background medium are complex at the wavelength scale of the probing waves. The relationship between seismic response and fluid saturation in a reservoir depends on many factors such as porosity and permeability of the reservoir rocks, viscosity and compressibility of the fluid, reservoir thickness and physical properties of the surrounding medium. But there is some general connection between the character of porous layer saturation and seismic response, which has to do with frequency content of reflected waves. We explore opportunities to use a frequency dependence of seismic reflections for underground reservoir imaging and monitoring.

Approach

We model a seismic response of dry and water saturated porous layer in laboratory using ultrasonic frequencies in order to find differences in seismic response due to character of fluid saturation. The effect of stronger reflections and travel time delays from water saturated layer is observed at low frequencies (Fig.1). We compared the results of laboratory modeling with "frictional-viscous" theoretical model and found that low (< 5) values of attenuation parameter Q and its approximate proportionality to frequency can explain the effect. The values of Q were determined in a separate experiment using recordings of a transmitted field for a thick porous layer, where water saturated layer had attenuation about two times higher then in a dry layer. These findings can be used for detecting and monitoring liquid saturated areas in thin porous layers

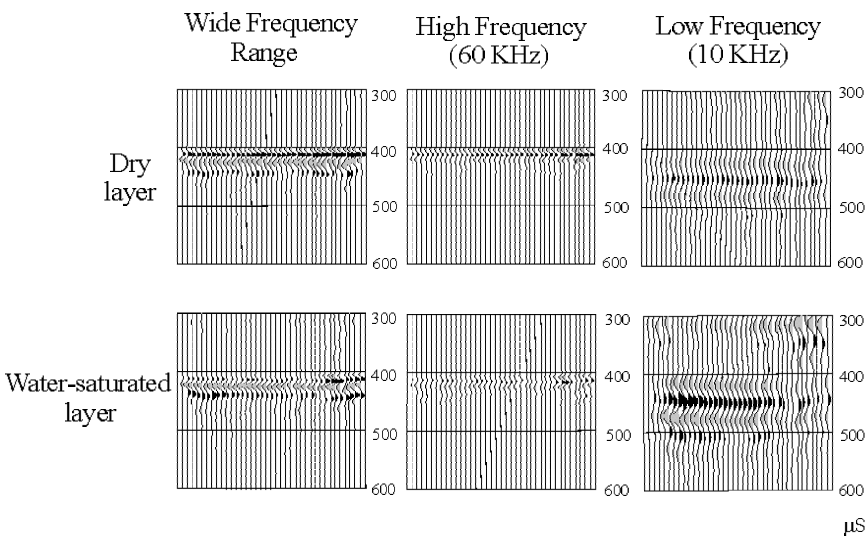

Fig.1 Data (left panels) and imaging of thin porous layers using common offset gathers by different filtering for dry and water saturated cases.

Measurements of Q factor for porous layer revealed very low values for both dry and water saturated cases. These values are close to seismic extremes but their existence can be explained by very small thicknesses, which can not absorb seismic wave energy completely. For the water saturated layer we found lower values of Q which showed increase in both "frictional" and " "viscous" attenuation. In all cases Q monotonically increases with frequency. While the behavior of reflection coefficient from attenuative layer is rather complex the ratio of reflection coefficients for water saturated and dry layers reveal strong and monotonic increase of reflection amplitude at low frequencies. The rate of this increase is more profound for the reflections from thin layer compare to the reflections from a thicker layer or a half space.

This reflection feature is a useful indicator of attenuative properties of thin porous layers. Attenuation for such layers strongly depends on a character of liquid saturation. The observed reflection travel time change fits theoretical predictions quite well. Layer with higher attenuation creates travel time delays increasing as frequency approaches zero. This property was observed on real data and can serve as an additional indication of liquid saturation in porous layers. The differences of dry and water saturated layer reflectivities are clearly seen at high and low frequency domains. Physical interpretation of "frictional" dissipation term remains uncertain. One of the applications will be time-lapse imaging of gas/steam and CO2 injection experiments in existing oil fields, with a goal of better understanding steam floods, CO2 sequestration, gas storage and geothermal reservoir exploitation.

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